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PRELIMINARY INVESTIGATIONS OF A METHOD TO PREDICT LINE-OF-SIGHT--ETC(U)
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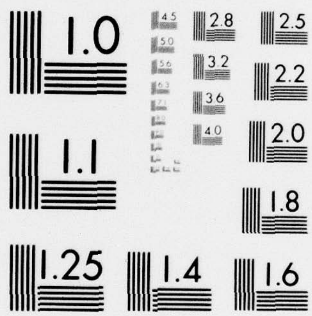

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Environmental Protection Research Division

Research Study Report

EA-10

PRELIMINARY INVESTIGATIONS OF A METHOD TO PREDICT LINE-OF-SIGHT CAPABILITIES

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6 **PRELIMINARY INVESTIGATIONS OF A METHOD TO PREDICT LINE-OF-SIGHT CAPABILITIES.**

10 Walter F. Wood, ~~Ph.D.~~ Joan B. Snell
Geographer

Joan B. Snell, M.A.
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Project No. 7-83-01-007

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ABSTRACT

FOREWORD

Recent basic research has shown that the geometry of the earth's surface is orderly. This research has progressed now to the point where it is possible to try for some practical applications of such knowledge.

This report discusses the application of terrain research to line-of-sight problems for both military and civilian operations. It deals with the design, construction and preliminary test of a mathematical model for predicting the availability of unobstructed lines of sight from high points into valleys out as far as 20 miles from the viewing point. Results of these tests indicate the merits of the model and the direction of further research. A theoretical discussion of this possible research is presented.

ABSTRACT

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PRELIMINARY INVESTIGATIONS OF A METHOD TO PREDICT
LINE-OF-SIGHT CAPABILITIES

1. Introduction

Recent developments in line-of-sight communication and surveillance equipment, both military and civilian, make it desirable to analyze the geometric properties of the earth's surface which affect operation of such equipment. To graphically study terrain obstructions to lines of sight for any significant portion of the world, would be impractical. It is desirable then, to develop a method for quickly ascertaining line-of-sight information. Predictive methods have been used successfully in other terrain studies and similar techniques may be applicable to line-of-sight analysis.(3,4)

2. The problem defined

To establish a method for predicting line-of-sight information, the capabilities of line-of-sight equipment and dimensions of terrain affecting it will be considered. A first analysis of the situation is limited to that type of equipment which has line-of-sight capabilities up to 20 miles over the smooth earth. This permits the consideration of a portion of the earth's surface as a plane, rather than as a segment of a sphere. Furthermore, since the bottoms of valleys are the most difficult points to see from any distance, the analysis is limited to the ability to see into valleys from a specified point (Fig. 1).

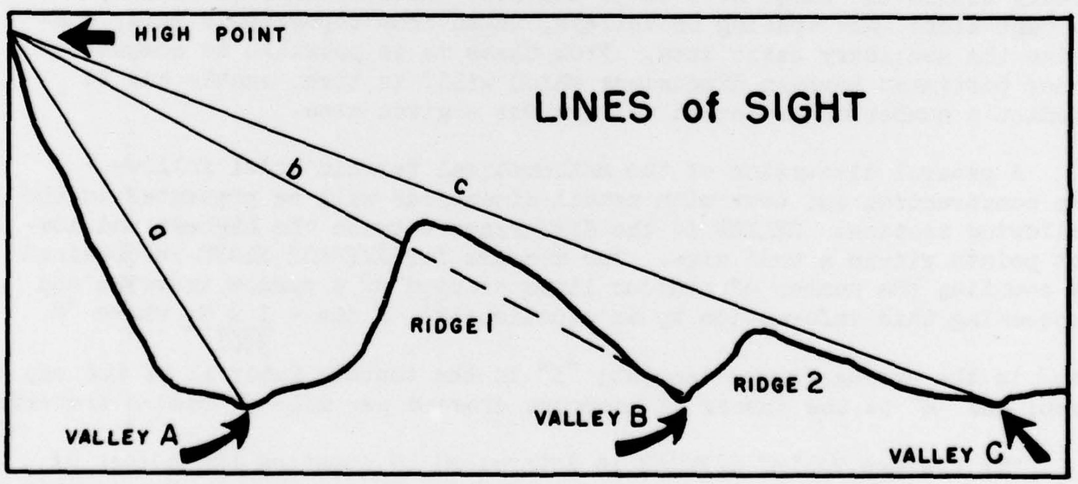

Fig. 1 Lines of sight (a,b, and c) projected from high point towards valleys (A,B, and C). Valleys A and C are visible from the high point, valley B is shadowed by ridge 1. Valley B is a protected valley.

The problem is now defined: "From the highest point within an area, how many valley bottoms can be seen at specified distances from that high point?" The results will be expressed as a number of protected (not seen) valleys.

Whether or not valleys can be seen from a point will depend on the character of the valleys and the nature of terrain lying between the high point and the valley. Therefore, the dimensions of terrain which most obviously affect line of sight will be the differences in elevation between the valleys and this high point (relief), the slope of the surface between them, the distance between valleys (valley spacing) and the depth of valleys. All of these dimensions can be computed from data available on topographic maps. With such information at hand, it is possible to construct a mathematical model of the terrain from which predictions of valley visibility can be made.

3. A mathematical model

a. Concepts under-lying construction of the model

A mathematical terrain model serves to simplify a landscape in accordance with a few actual dimensions of a particular area. The model devised for this problem assumes that all the valleys within the area are of equal depth with the same side-slope, all are parallel, all are equally spaced, and the ridge tops between valleys are the same distance apart as the valley bottoms. It is further assumed that angles made by the intersection of lines-of-sight and any given valley are equally likely within the range of 0 to 90 degrees. Measurements of relief, average slope, and spacing of valleys, taken from topographic maps, comprise the necessary basic data. From these it is possible to compute other pertinent terrain dimensions which will, in turn, enable one to predict a number of protected valleys for a given area.

A general discussion of the mathematical terrain model follows. The construction and test with actual dimensions will be presented in the following section. RELIEF is the difference between the highest and lowest points within a unit area. The measure for AVERAGE SLOPE is obtained by counting the number of contour lines crossed by a random traverse and processing this information by an equation:[2] $S \tan = \frac{I \times M}{3361}$; where "S tan" is the average slope tangent; "I" is the contour interval of the map in feet; and "M" is the number of contours crossed per mile of random traverse.

The average VALLEY SPACING is determined by counting the number of valleys along a random traverse and processing this number by the equation: $S = \frac{T + N}{1.57}$; where "S" is the average valley spacing; "T" is the length of

traverse; "N" is the number of valleys along the traverse. The constant "1.57" compensates for the fact that the valleys do not intersect a circle at right angles.

Other dimensions necessary for solving the line-of-sight problem include the distance from a ridge top to a valley bottom. Assuming that ridge tops are the same distance apart as valley bottoms, the RIDGE - VALLEY DISTANCE within the area will be one-half the valley spacing. An average VALLEY DEPTH can be computed from the average slope and the ridge-valley distance. For instance, the average slope tangent of the area is .15 and the ridge-valley distance is one mile, the valleys are .15 miles deep. (.15 x 1 = .15)

The angle a line of sight makes between the highest and lowest points at a given distance also contributes to the solution of valley visibility. Therefore, another dimension, ANGLE OF SIGHT must be built into the model. The tangent of an angle of sight is obtained by dividing the relief of an area by the distance between the high and low points.

When all valleys have the same depth and spacing, and are assumed to be parallel to each other, the only other variable which will determine whether or not a given valley is seen from a particular point is the angle at which the valley enters the area under observation. To compute this angle, one other dimension is required, that is, the distance to the nearest ridge along a line of sight. The RIDGE-INTERFERENCE DISTANCE is the hypotenuse of a right triangle, one leg of which is the ridge-valley distance. The sine of the ANGLE OF VALLEY ENTRANCE can then be computed by dividing the ridge-valley distance by the ridge-interference distance. It is the angle of valley entrance which is converted to a percent of total valleys protected.

The valley which enters an area directly toward the point from which a line of sight is projected, that is, the valley which is an extension of the line of sight, will always be seen. For any given valley depth, spacing and angle of sight, there is a given angle of entrance at which a valley can just barely be seen. Those valleys which make an even more acute angle with the line of sight can also be seen, but those which are at a greater angle cannot be seen. Thus, when this angle of valley entrance divides a right triangle, said to contain all the valleys in a given area, into two parts, the section of the triangle which lies to one side of the line formed by this angle, is analagous to the proportion of valleys seen in that area; the section of the triangle which lies to the other side of this line, is analagous to the proportion of valleys which cannot be seen.

b. <u>The model applied to specific areas</u>

In order to test its validity, the mathematical model described above was applied to two areas of widely contrasted terrain. The areas

selected were in New England (Glens Falls sheet, 1:250,000 AMS series, contour interval 100') and the Colorado Plateau (Grand Canyon sheet, 1:250,000 AMS series, contour interval 200"). The Glens Falls sheet represents a mountainous area of many, deep, closely-spaced valleys and steep slopes. In contrast, the Grand Canyon region is plateau country with fewer, widely-spaced valleys and less steep slopes.

For both areas, the following technique for gathering data and predicting number of protected valleys was followed:

(1) The highest elevation on the sheet was selected as the point from which lines of sight would be projected towards the valleys within the area.

(2) The study was limited to a circular area having a radius of 20 miles with the highest point on the sheet as the center of the circle.

(3) 20 concentric circles were drawn at intervals of 1 mile from the highest point.

(4) Every stream (indicating a valley) crossing a circle was analyzed to see whether or not it was visible from the highest point. Lines of sight were actually projected from the highest point to each of the streams where it crossed a circle.* When elevations lying between the high point and the stream obstructed the line of sight, the valley was considered protected. (Table I)

(5) The number of valleys crossing each circle were counted; the relief and average slope were computed for each circle, and these data were recorded.

(6) The model was constructed for each circle by computing valley spacing, ridge-valley distance, valley depth, angle of sight, ridge-interference distance and angle of valley entrance.

(7) The angle of valley entrance was converted to a predicted number of protected valleys. (Table II and Figure 2 illustrate these methods. The 20-mile circle of the Glens Falls sheet is used as an example.)

* A new device which permits the analysis of line-of-sight problems without drawing earth profiles, was used for this phase of the study. (1)

TABLE I

NUMBER OF PROTECTED VALLEYS DETERMINED FROM LINE-OF-SIGHT OBSERVATIONS

	GLENS FALLS SHEET AMS 1:250,000			GRAND CANYON SHEET AMS 1:250,000		
Radius of Circle	Number of Valleys Crossing Circles	Number of Protected Valleys	Percent Protected	Number of Valleys Crossing Circles	Number of Protected Valleys	Percent Protected
1 mile	4	1	25	0	0	0
2 miles	7	4	57	1	0	0
3 miles	12	9	75	3	1	33
4 miles	10	7	70	3	1	33
5 miles	13	9	69	6	4	67
6 miles	12	5	42	8	3	38
7 miles	20	12	60	10	5	50
8 miles	25	20	80	11	5	45
9 miles	17	10	59	8	5	63
10 miles	21	9	43	16	11	69
11 miles	27	15	56	16	10	63
12 miles	33	20	61	17	10	59
13 miles	32	19	59	23	11	48
14 miles	36	27	75	24	14	58
15 miles	32	22	69	26	17	65
16 miles	35	27	77	29	18	62
17 miles	40	34	85	33	19	58
18 miles	44	42	95	35	13	37
19 miles	41	36	88	38	10	26
20 miles	41	40	98	35	17	49

TABLE II

COMPUTATIONS FOR CONSTRUCTING TERRAIN MODEL TO PREDICT NUMBER OF PROTECTED VALLEYS

20-mile circle, Glens Falls sheet, AMS 1:250,000

TERRAIN FACTORS	FORMULA for COMPUTING	COMPUTATIONS	RESULTS
A Radius of circle			20 mi.
B Circumference of circle	$2\pi r$	2 x 3.1416 x 20	125.66 mi.
C Number of valleys crossing circle			41
D Relief (in miles)	Highest elevation -Lowest elevation	4000 ft. - 330 ft. = 3670 ft.; 3670 ÷ 5280	.6951 mi.
E Average slope tangent	$\frac{\text{contour counts / mi. x contour interval}}{3361}$	$\frac{4.84 \text{ cc/mi. x } 100'}{3361}$	.1440
F Valley spacing	$\frac{\text{traverse} \div \text{valley number}}{1.57}$	$\frac{125.66 \div 41}{1.57}$	1.9512 mi.
G Ridge-valley distance	$\frac{\text{valley spacing}}{2}$	$\frac{1.9512}{2}$	.9756 mi.
H Valley depth	average slope x ridge-valley distance	.1440 x .9756	.1405 mi.
I Angle of sight (tangent)	$\frac{\text{relief}}{\text{radius}}$	$\frac{.6951}{20}$	.0348
J Ridge-interference distance	$\frac{\text{valley depth}}{\text{angle of sight}}$	$\frac{.1405}{.0348}$	4.0374 mi.
K Angle of valley entrance (sine)	$\frac{\text{ridge-valley distance}}{\text{ridge-interference distance}}$	$\frac{.9756}{4.0374}$	.2416
L Angle of valley entrance (degrees)			13.98°
M Percent of valleys seen*	angle of valley entrance ÷ 90°	$\frac{13.98}{90}$	15.53%
N Percent of valleys protected	100% - % of valleys seen	100% - 15.53%	84.47%
O Predicted number of protected valleys	% of protected valleys seen	84.47% x 41	35

* Computing the percent of valleys seen is facilitated on a desk-type calculator by using the reciprocal of 90 (1.1111) as a multipler. Thus, this formula becomes: Angle of valley entrance x 1.1111.

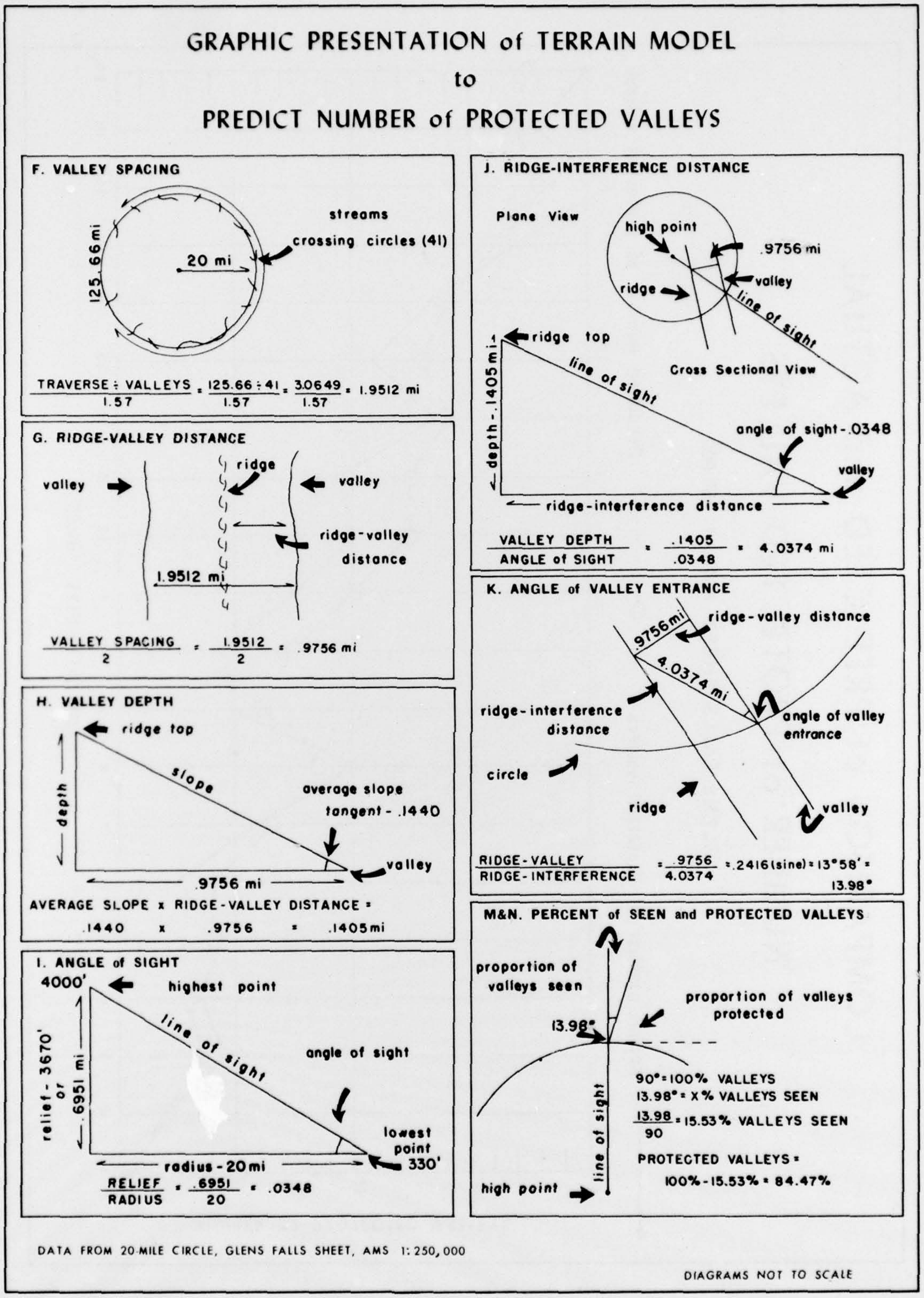
GRAPHIC PRESENTATION of TERRAIN MODEL
to
PREDICT NUMBER of PROTECTED VALLEYS
F. VALLEY SPACING
125.66 mi
20 mi
streams
crossing circles (41)
TRAVERSE ÷ VALLEYS / 1.57 = 125.66 ÷ 41 / 1.57 = 3.0649 / 1.57 = 1.9512 mi
G. RIDGE-VALLEY DISTANCE
valley
ridge
valley
ridge-valley
distance
1.9512 mi
VALLEY SPACING / 2 = 1.9512 / 2 = .9756 mi
H. VALLEY DEPTH
ridge top
depth
slope
average slope
tangent - .1440
valley
.9756 mi
AVERAGE SLOPE x RIDGE-VALLEY DISTANCE =
.1440 x .9756 = .1405mi
I. ANGLE of SIGHT
4000'
highest point
relief - 3670' or .6951 mi
line of sight
angle of sight
lowest
point
330'
radius - 20mi
RELIEF / RADIUS = .6951 / 20 = .0348
J. RIDGE-INTERFERENCE DISTANCE
Plane View
high point
.9756 mi
valley
ridge
line of sight
ridge top
depth - .1405 mi
line of sight
Cross Sectional View
angle of sight - .0348
valley
ridge-interference distance
VALLEY DEPTH / ANGLE of SIGHT = .1405 / .0348 = 4.0374 mi
K. ANGLE of VALLEY ENTRANCE
.9756 mi
ridge-valley distance
4.0374 mi
ridge-interference
distance
angle of valley
entrance
circle
ridge
valley
RIDGE-VALLEY / RIDGE-INTERFERENCE = .9756 / 4.0374 = .2416 (sine) = 13°58' = 13.98°
M&N. PERCENT of SEEN and PROTECTED VALLEYS
proportion of
valleys seen
proportion of valleys
protected
13.98°
90° = 100% VALLEYS
13.98° = X% VALLEYS SEEN
13.98 / 90 = 15.53% VALLEYS SEEN
PROTECTED VALLEYS =
100% - 15.53% = 84.47%
line of sight
high point
DATA FROM 20-MILE CIRCLE, GLENS FALLS SHEET, AMS 1:250,000
DIAGRAMS NOT TO SCALE

Fig. 2

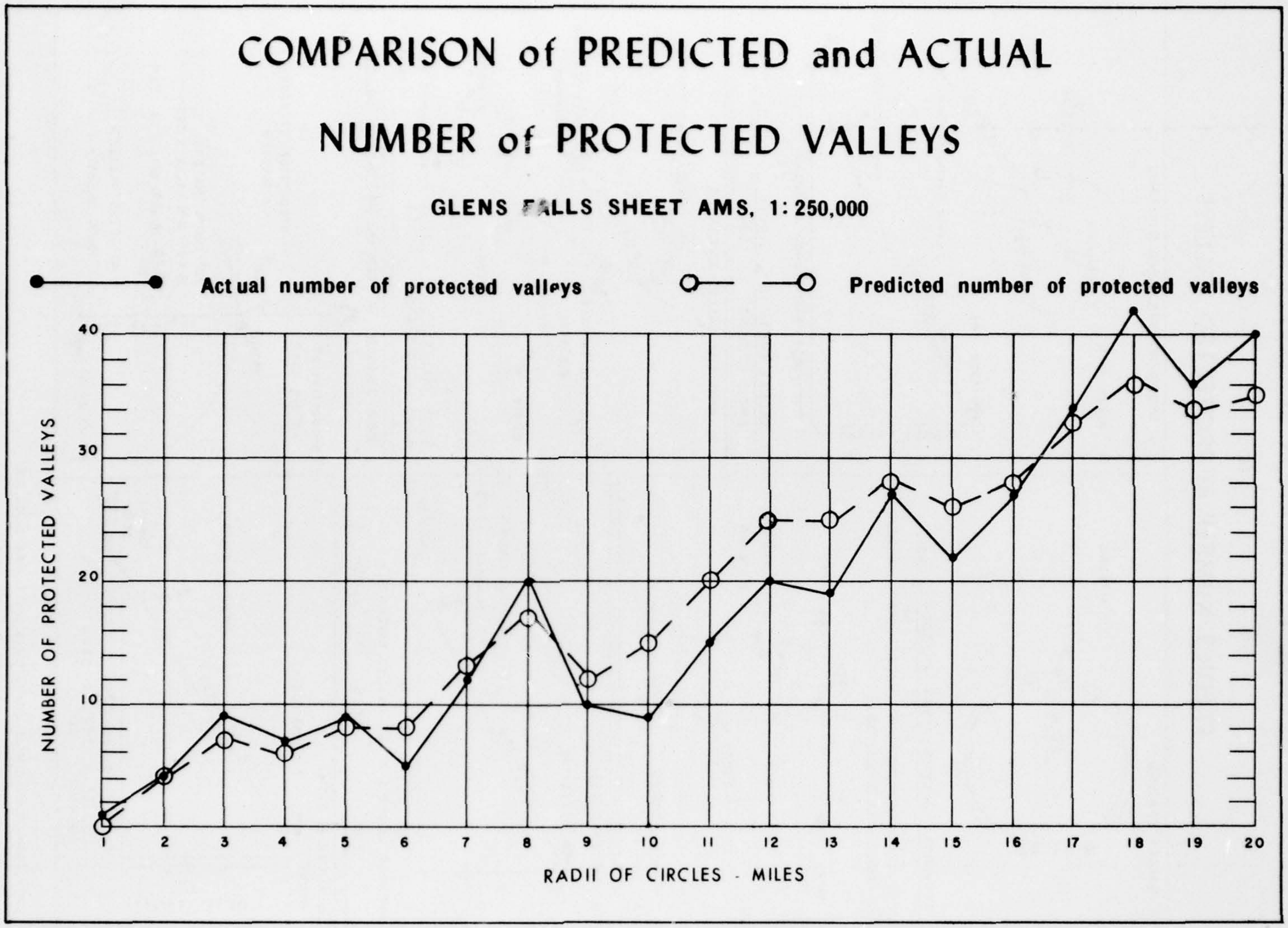
COMPARISON of PREDICTED and ACTUAL
NUMBER of PROTECTED VALLEYS
GLENS FALLS SHEET AMS, 1: 250,000
Actual number of protected valleys
Predicted number of protected valleys
NUMBER OF PROTECTED VALLEYS
RADII OF CIRCLES - MILES

Fig. 3

COMPARISON of PREDICTED and ACTUAL NUMBER of PROTECTED VALLEYS

GRAND CANYON SHEET, AMS, 1:250,000

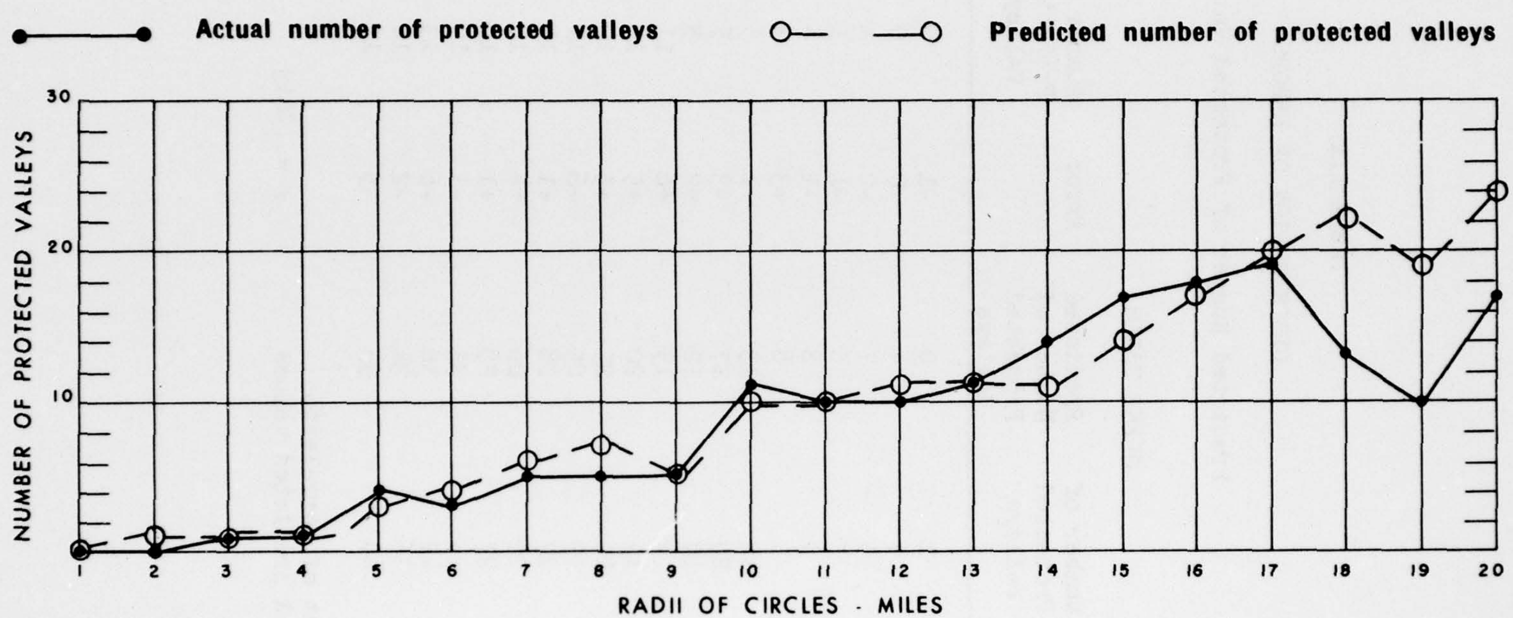

Fig. 4

TABLE III

DISTRIBUTION OF ERRORS

Predicted Number of Protected Valleys

Radius of Circle	GLENS FALLS Number of Protected Valleys	GLENS FALLS Predicted Number of Protected Valleys	GLENS FALLS Error	GRAND CANYON Number of Protected Valleys	GRAND CANYON Predicted Number of Protected Valleys	GRAND CANYON Error
1 mile	1	0	-1	0	0	0
2 miles	4	4	0	0	1	+1
3 miles	9	7	-2	1	1	0
4 miles	7	6	-1	1	1	0
5 miles	9	8	-1	4	3	-1
6 miles	5	8	+3	3	4	+1
7 miles	12	13	+1	5	6	+1
8 miles	20	17	-3	5	7	+2
9 miles	10	12	+2	5	5	0
10 miles	9	15	+6	11	10	-1
11 miles	15	20	+5	10	10	0
12 miles	20	25	+5	10	11	+1
13 miles	19	25	+6	11	11	0
14 miles	27	28	+1	14	11	-3
15 miles	22	26	+4	17	14	-3
16 miles	27	28	+1	18	17	-1
17 miles	34	33	-1	19	20	+1
18 miles	42	36	-6	13	22	+9
19 miles	36	34	-2	10	19	+9
20 miles	40	35	-5	17	24	+7
Coefficient of correlation: actual and predicted values			r = .9613			r = .8597

c. Validity of the model

Comparisons of the predicted and actual number of protected valleys for both the Glens Falls and Grand Canyon areas are shown in Figures 3 and 4. Inspection of these graphs reveals that the trend of prediction follows the trend of what actually occurs. In the absence of any evidence to the contrary, it can be concluded that the model is valid in theory, and unless further tests prove otherwise, it can be considered applicable to all terrain.

Although the trend line (Fig. 3 and 4) indicate that the model is promising, improvements can probably be made. Further research into the line-of-sight problem will seek means of overcoming the existing error (Table III) and extending the application of line-of-sight information.

4. Suggested lines of study for further investigations into the problem

a. Randomness of valley entrances

The construction of the model and subsequent predictions are based on the assumption that the angles at which valleys cross a line-of-sight have a random distribution. Thus, the first consideration in perfecting the model would be the analysis of any deviation from randomness exhibited by these angles. Probability laws will definitely limit the accuracy of any improvements made in the model and it should be known how important this is so that effort is not wasted in trying to obtain a performance level which is impossible.

b. Blocking effect

In developing the model, the only height of land considered capable of blocking a line of sight into a valley was the ridge nearest the valley. A study of the actual lines of sight, and the pieces of terrain which blocked them, showed that in many cases, high land further away from the valley exercised the blocking effect. The relative position of such high land, with regard to sighting point and valley, requires further investigation. The pattern of prediction errors (Figs. 3 and 4) suggests that the grain of the landscape is involved.

Landscape grain is determined by the spacing of the major ridges and valleys. It is computed by selecting a random point on a map and drawing circles at even increments of diameter around this point. The relief for each circle is plotted against its diameter and the points connected with a straight line. At some length of diameter, a knick point will occur in this line, after which, with increasing size of area, there is no appreciable increase in relief. The length of diameter at which the knick point occurs is the grain of the area. (Fig. 5)

Grain in the Glens Falls area occurs at about the 7-mile circle. Figure 3 and Table III show that the model worked best in the first 7 circles, with a tendency toward under-prediction. The next group of 7 circles tended toward over-prediction and less accurate predictions. After about the 14-mile circle, the performance of the model was more like that of the first 7 circles. In the Grand Canyon, the grain is at the 14 mile circle. From Figure 4 and Table III, good performance of the model is evident up to the 14-mile circle, after which the performance becomes poorer and tends toward over-prediction.

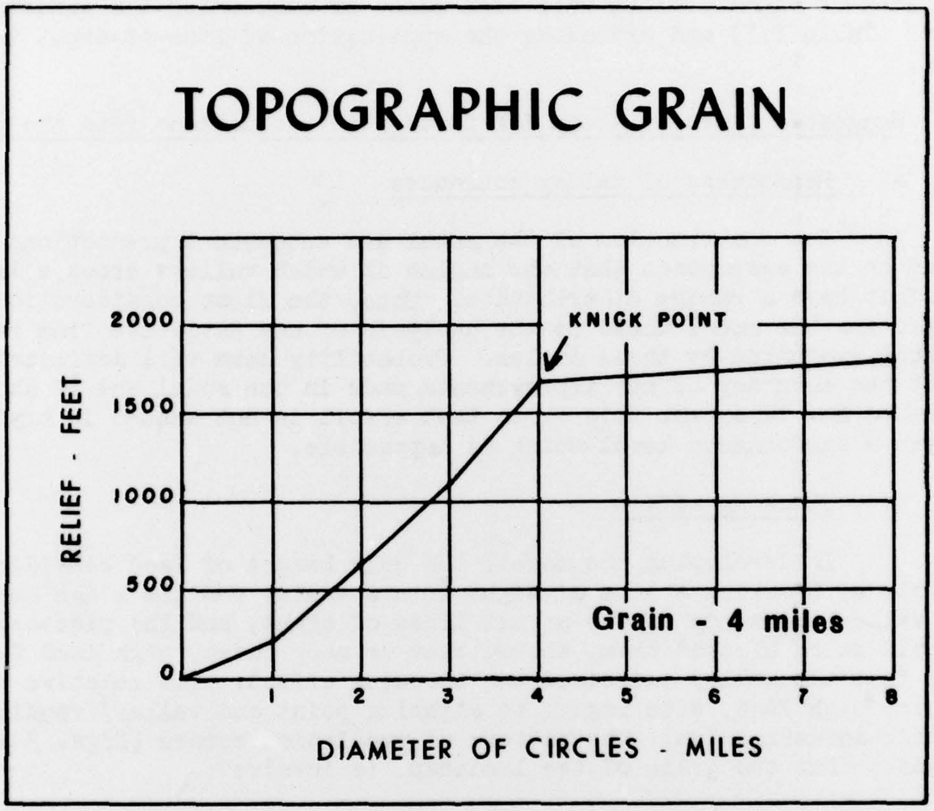

Fig. 5 Landscape grain is determined by plotting relief of a circular area against diameter of the circle and noting the diameter at which a knick point occurs.

c. <u>Selection of a point from which to project lines-of-sight</u>

To develop the technique described above, the highest point within the area under observation was selected as the point from which

lines of sight were projected. Since no land is higher than this point, it is presumably, the optimum location from which to keep the entire area under surveillance. The question arises, however, as to the effectiveness of lines-of-sight when the sighting point is at some elevation other than the highest in the area. In an attempt to answer this query, the elevations of over 600 random points from the 20-mile circle on the Glens Falls sheet were plotted against percent of area. Thus a chart was produced that shows the percent of total area which lies above any specified elevation (Fig. 6). This chart can be used as an aid to obtain an impression of the suitability of a sighting point at some elevation other than the highest within the area.

For example, if a sighting point were selected at an elevation of 2920 feet, 1% of the total area would lie above it. Lines of sight projecting outward in a horizontal plane from this point would encounter the higher land, thereby reducing the ability to see into valleys by some relationship to that 1% of land area lying above the sighting point. Or, if a sighting point were selected at 2000 feet elevation, 20% of the land area would lie above it. This 20% of higher land would interrupt lines of sight and further reduce the amount of total area which could be traversed by lines of sight. The extent to which these percentages of higher land interfere with lines of sight is a further ramification of the blocking effect, and requires additional investigation. Preliminary thought on the subject seems to indicate that the linear dimensions of this projecting terrain are more closely related to blocking effect than the area and volume involved.

d. The effect of more than one sighting point

If a sighting point is established at a place lower than the highest elevation within an area, and a horizontally projected line of sight is interrupted so that 90% of the area is visible, and 10% is invisible, it is to be expected that another sighting point at the same elevation could be located so that 90% of the previously invisible 10% could be seen. The two sighting points together should then have the capability of seeing 99% of the total area. Again, if a first sighting point is placed so that 80% of the area is visible and 20% is invisible, a second sighting point properly located at the same elevation should see 80% of the invisible 20%. 96% of the total area should be visible to the two points together.

e. Towards simplifying analysis of other areas

The evaluation of areas in regard to line-of-sight capabilities may not require the detailed analysis which has been described here. For some types of operation, it may be necessary to know only average slope, valley depth and valley spacing in order to evaluate the expected

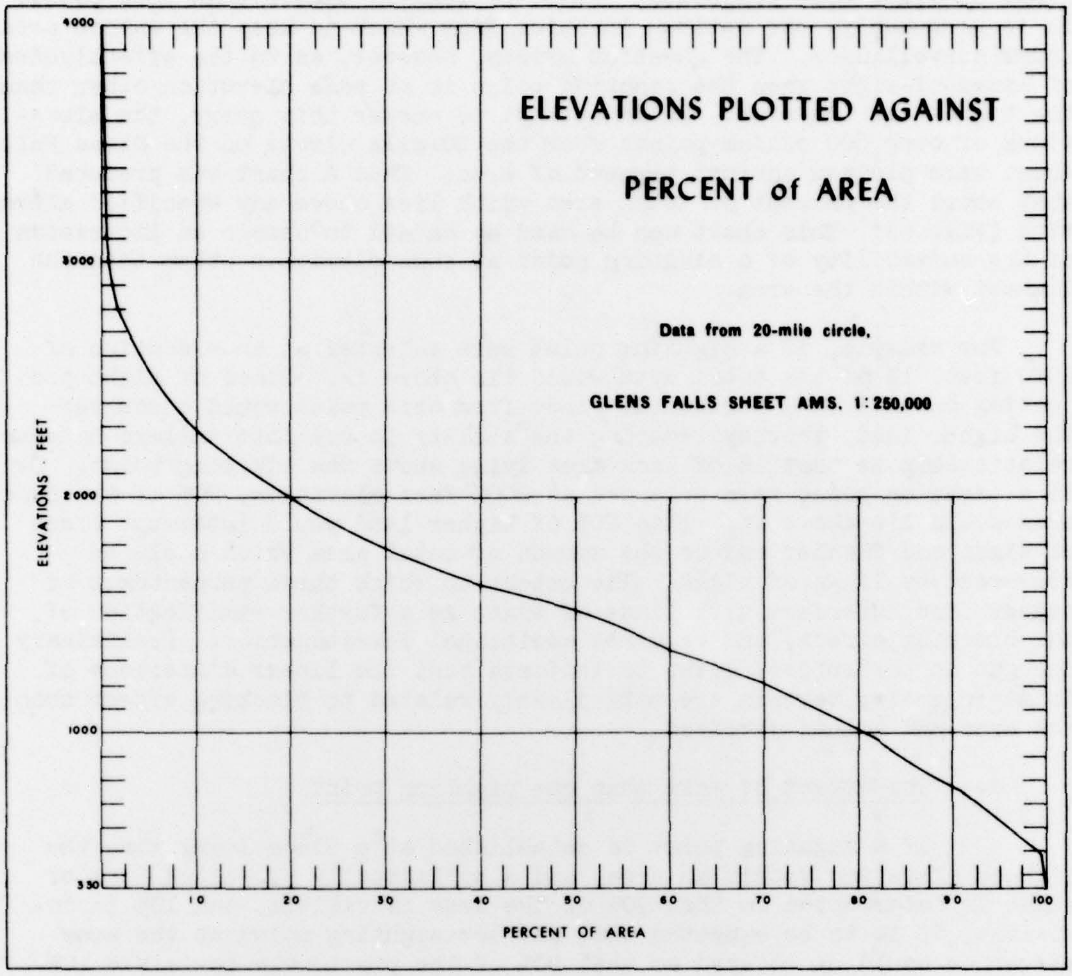

Fig. 6

success of that operation. As has been previously demonstrated, values for average slope and average spacing of valleys are not difficult to obtain. From these dimensions, average valley depth can be computed.

It is in the nature of these three dimensions that if any two are given, there is only one figure which will fulfill the dimensions of the third. Therefore, the relationships of these three dimensions can be graphed in the form of a nomograph. Depending on the specific nature of a line-of-sight problem, an area can be evaluated by consulting the nomograph (Fig. 7). For example, a valley depth of 500 feet is required for a certain operation. Is an area with average slope tangent of .08 and a valley spacing of 1.2 miles capable of supporting such an operation? A quick look at the nomograph (Fig. 7) will indicate that this area is not suitable, since valley depth for such an area is only 250 feet.

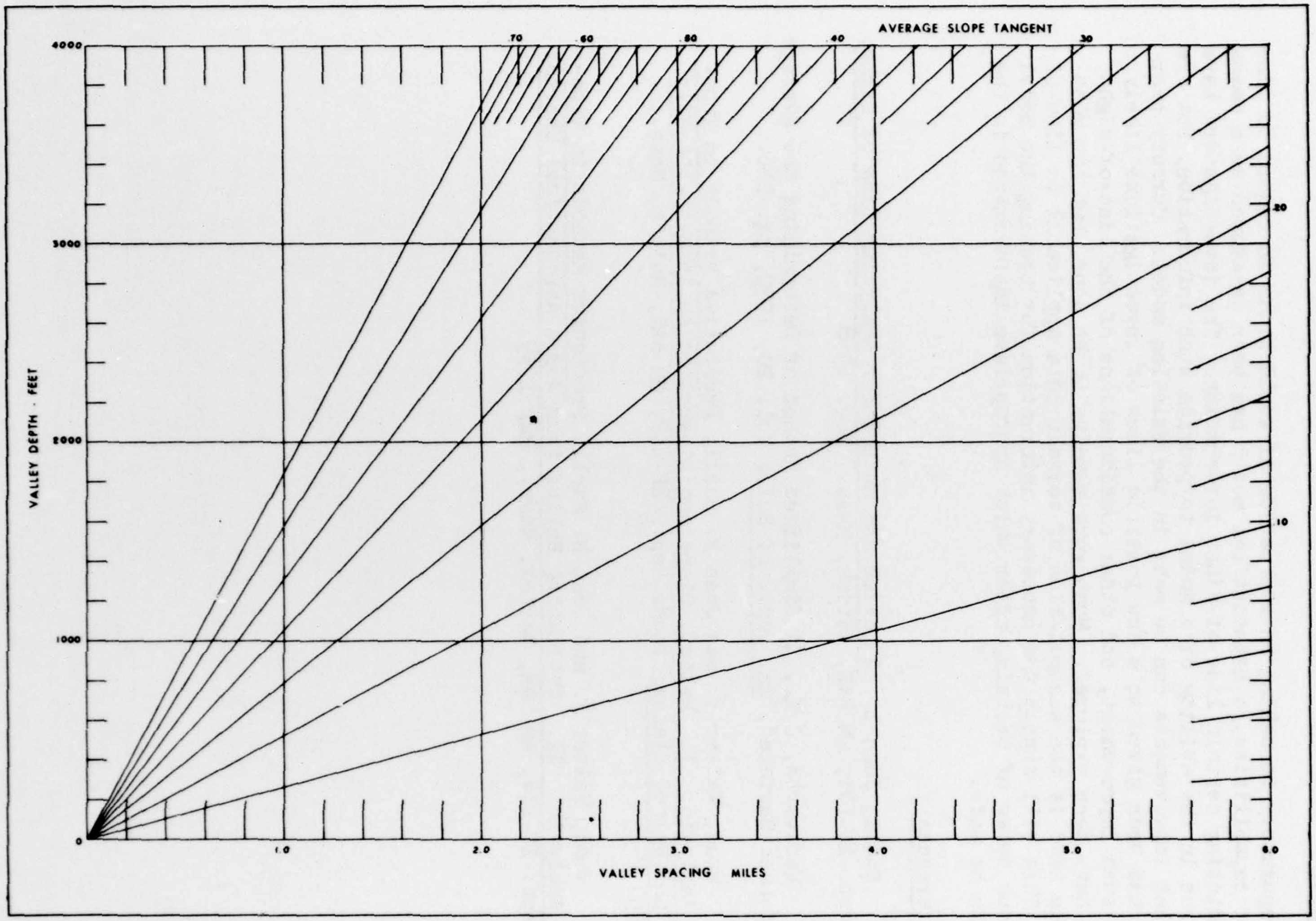

Fig. 7 Nomograph to determine the numerical relationships of valley depth, valley spacing, and average slope.

5. Summary

Preparatory to making an evaluation of world areas in regard to line-of-sight capabilities, a mathematical model has been developed as a means for predicting certain line-of-sight information. The investigators have confidence in the ability of a model to provide such information, but are aware that improvements can be made in the existing model. Cursory examination has been given to a few possible lines of investigations likely to lead to such improvement, and other considerations of the line-of-sight problem have been explored. Much work remains to be done, but the most immediate need is the accumulation of terrain data applicable to line-of sight. This will supply the necessary information for testing the model in various types of terrain, after which appropriate improvements in the model can be made.

6. References

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